ENERGY REQUIREMENTS FOR CONVENTIONAL AND ADVANCED WASTEWATER TREATMENT

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Abstract

A comparison of the energy requirements for conventional and advanced wastewater treatment is illustrated on the basis of the operational energy demand of these processes. Energy involved in the production of lime, alum and chlorine was added to the electrical energy showing a substantial increase in total energy demand for the advanced treatment processes.

Energy considerations may be necessary in order to make decisions on the types of treatment systems to be utilized in the future.

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1.0 Introduction

The shortage of fossil fuels and the accompanying high cost of energy has led to an emphasis on energy conservation with a reevaluation of process energy requirements in an attempt to locate potential areas for energy conservation. Past studies involving wastewater treatment systems have relegated energy requirements to design specification values and operating cost estimates without any summation of the total energy demand of the system.

A complete comparison of energy consumption for a process or system requires knowledge of the "capital" energy requirements (the energy required to fabricate the process units from primary construction materials) as well as the energy required for operation and maintenance of the equipment over its functioning lifetime.

To date, evaluation of capital energy requirements for the equipment manufacture is difficult due to insufficient data, although it can be expected that this data will be collected in the near future for this type of estimation purpose. This study, then, is concerned with the operational energy requirements for conventional and advanced wastewater treatment systems. The energy demands of such processes encompass the energy requirements of process auxillaries such as pumps, blowers, agitators, mixers, rotating rakes and skimmers, as well as for major pieces of equipment such as vacuum filters, vibrating screens centrifugal separators, etc.

To complete a study of this nature, the production of chemicals entails an operating energy according to the amount or dosage used in the process. Chemicals such as chlorine, alum, lime, ferric chloride, polyelectrolytes, etc., are all accounted for in the operating cost estimates and must also be taken into account in

the operating energy calculation. This study illustrates the approach taken to compare operational energy requirements for several configurations of conventional and advanced waste treatment processes.

2.0 Previous Studies on Energy Consumption

Most studies involving energy and waste treatment have been concerned with energy recovery, such as gas production from anaerobic processes and sludge utilization as a combustible fuel. An E.P.A. study by Smith[1] examined the problem of energy and power consumption involved in municipal wastewater treatment. In his investigation, electrical power for complete plants was estimated by adding the power consumption for individual processes and plant utilities. Several configurations for conventional and advanced treatment systems were analyzed and compared. Three types of conventional treatment plants were studied:

1. Primary
2. Activated Sludge
3. High Rate Trickling Filter

In addition, three sludge handling and disposal schemes were considered. Tables 1 to 5[1] list the electrical requirements for each unit operation and the total power consumptions for 1, 10 and 100 mgd* plants. Figure 1 shows a plot of these data for each system and sludge handling scheme.

Similarly, the estimates of power consumption for various alternative tertiary treatment trains are shown in Tables 6 to 8[1] and these data plotted in Figure 2 for 1, 10 and 100 mgd capacities. Included in these estimates are the power consumptions for alum sludge handling and lime sludge dewatering and recalcination.

This information provides the power requirements per unit in the process trains as well as the power requirements for the total system. Lund,[2] in his handbook has suggested that a complete wastewater system may require either from 5 to 10 kw/1000 gpm

* millions U.S. gallons per day

TABLE 1

ELECTRICAL ENERGY REQUIREMENTS FOR WASTEWATER TREATMENT PLANTS

TYPE OF PLANT Primary	SLUDGE HANDLING SCHEME I Killowatt-hours/day		
PLANT SIZE	1 mgd	10 mgd	100 mgd
PRELIMINARY TREATMENT			
Bar Screens	1.53	1.53	10.70
Comminutors	15.30	61.00	204.00
Grit Removal	1.70	3.40	34.00
INFLUENT PUMPING (30 ft TDH)	153.00	1,451.00	12,933.00
PRIMARY SEDIMENTATION (800 gpd/sq. ft.)	30.60	122.00	734.00
TRICKLING FILTERS			
Recirculation Pumping			
Final Sedimentation			
ACTIVATED SLUDGE PROCESS			
Diffused Air			
Recirculation Pumping (50%, 17.5 ft)			
Final Settlers (800 gpd/sq. ft.)			
CHLORINATION	0.72	82.40	829.00
SLUDGE HANDLING AND DISPOSAL			
Sludge Pumping	0.64	6.40	64.00
Gravity Thickeners	10.20	20.40	30.60
Air Flotation Thickeners			
Anaerobic Digesters			
Mixing	84.00	212.00	678.00
Heating	17.60	122.40	788.00
Vacuum Filtration			
Multiple Hearth Incineration			
LIGHTS AND MISCELLANEOUS POWER	57.00	210.00	2400.00
TOTAL Kilowatt-hours/day	372.00	2293.00	18,700.00

TABLE 2

ELECTRICAL ENERGY REQUIREMENTS FOR WASTEWATER TREATMENT PLANTS

TYPE OF PLANT Primary	SLUDGE HANDLING SCHEME II Killowatt-hours/day		
PLANT SIZE	1 mgd	10 mgd	100 mgd
PRELIMINARY TREATMENT			
Bar Screens	1.53	1.53	10.70
Comminutors	15.30	61.00	204.00
Grit Removal	1.70	3.40	34.00
INFLUENT PUMPING (30 ft TDH)	153.00	1451.00	12,933.00
PRIMARY SEDIMENTATION (800 gpd/sq. ft.)	30.60	122.00	734.00
TRICKLING FILTERS			
Recirculation Pumping			
Final Sedimentation			
ACTIVATED SLUDGE PROCESS			
Diffused Air			
Recirculation Pumping (50%, 17.5 ft)			
Final Settlers (800 gpd/sq. ft.)			
CHLORINATION	0.72	82.40	829.00
SLUDGE HANDLING AND DISPOSAL			
Sludge Pumping	0.64	6.40	64.00
Gravity Thickeners	10.20	20.40	30.60
Air Flotation Thickeners			
Anaerobic Digesters			
Mixing	84.00	212.00	673.00
Heating	17.60	122.40	788.00
Vacuum Filtration	10.40	108.00	847.00
Multiple Hearth Incineration	28.40	152.40	1448.00
LIGHTS AND MISCELLANEOUS POWER	57.00	210.00	2,400.00
TOTAL Kilowatt-hours/day	411.00	2,343.00	21,000.00

TABLE 3

ELECTRICAL ENERGY REQUIREMENTS FOR WASTEWATER TREATMENT PLANTS

TYPE OF PLANT Activated Sludge	SLUDGE HANDLING SCHEME II Killowatt-hours/day		
PLANT SIZE	1 mgd	10 mgd	100 mgd
PRELIMINARY TREATMENT			
Bar Screens	1.53	1.53	10.70
Comminutors	15.30	61.00	204.00
Grit Removal	1.70	3.40	34.00
INFLUENT PUMPING (30 ft TDH)	153.00	1,451.00	12,933.00
PRIMARY SEDIMENTATION (800 gpd/sq. ft.)	30.60	122.00	734.00
TRICKLING FILTERS			
Recirculation Pumping			
Final Sedimentation			
ACTIVATED SLUDGE PROCESS			
Diffused Air	532.00	5,320.00	53,200.00
Recirculation Pumping (50%, 17.5 ft)	45.00	423.00	3,131.00
Final Settlers (800 gpd/sq. ft.)	30.60	122.00	734.00
CHLORINATION	.72	.72	266.00
SLUDGE HANDLING AND DISPOSAL			
Sludge Pumping	2.66	26.60	266.00
Gravity Thickeners	10.20	20.40	40.80
Air Flotation Thickeners			
Anaerobic Digesters			
Mixing	106.00	334.00	1,122.00
Heating	17.60	122.40	788.00
Vacuum Filtration	57.00	346.00	3,325.00
Multiple Hearth Incineration	54.00	245.00	1,905.00
LIGHTS AND MISCELLANEOUS POWER	57.00	210.00	2,400.00
TOTAL Kilowatt-hours/day	1,115.00	8,809.00	81,094

TABLE 4

ELECTRICAL ENERGY REQUIREMENTS FOR WASTEWATER TREATMENT PLANTS

TYPE OF PLANT Activated Sludge	SLUDGE HANDLING SCHEME III Killowatt-hours/day		
PLANT SIZE	1 mgd	10 mgd	100 mgd
PRELIMINARY TREATMENT			
Bar Screens	1.53	1.53	10.70
Comminutors	15.30	61.00	204.00
Grit Removal	1.70	3.40	34.00
INFLUENT PUMPING (30 ft TDH)	153.00	1,451.00	12,933.00
PRIMARY SEDIMENTATION (800 gpd/sq. ft.)	30.60	122.00	734.00
TRICKLING FILTERS			
Recirculation Pumping			
Final Sedimentation			
ACTIVATED SLUDGE PROCESS			
Diffused Air	532.00	5,320.00	53,200.00
Recirculation Pumping (50%, 17.5 ft)	45.00	423.00	3,131.00
Final Settlers (800 gpd/sq. ft.)	30.60	122.00	734.00
CHLORINATION	.72	.72	266.00
SLUDGE HANDLING AND DISPOSAL			
Sludge Pumping	2.66	26.60	266.00
Gravity Thickeners	10.20	20.40	30.60
Air Flotation Thickeners	70.00	608.00	4,692.00
Anaerobic Digesters			
Mixing			
Heating			
Vacuum Filtration	60.00	346.00	3,947.00
Multiple Hearth Incineration	75.00	328.00	3,280.00
LIGHTS AND MISCELLANEOUS POWER	57.00	210.00	2,400.00
TOTAL Kilowatt-hours/day	1,085.00	9,044.00	85,862.00

TABLE 5

ELECTRICAL ENERGY REQUIREMENTS FOR WASTEWATER TREATMENT PLANTS

TYPE OF PLANT high rate trickling filter	SLUDGE HANDLING SCHEME II Killowatt-hours/day		
PLANT SIZE	1 mgd	10 mgd	100 mgd
PRELIMINARY TREATMENT			
Bar Screens	1.53	1.53	10.70
Comminutors	15.30	61.00	204.00
Grit Removal	1.70	3.40	34.00
INFLUENT PUMPING (30 ft TDH)	153.00	1,451.00	12,933.00
PRIMARY SEDIMENTATION (800 gpd/sq. ft.)	30.60	122.00	734.00
TRICKLING FILTERS			
Recirculation Pumping	183.00	1740.00	15,519.00
Final Sedimentation	30.60	122.00	734.00
ACTIVATED SLUDGE PROCESS			
Diffused Air			
Recirculation Pumping (50%, 17.5 ft)			
Final Settlers (800 gpd/sq. ft.)			
CHLORINATION	.72	.72	266.00
SLUDGE HANDLING AND DISPOSAL			
Sludge Pumping	2.66	26.60	266.00
Gravity Thickeners	10.20	20.40	40.80
Air Flotation Thickeners			
Anaerobic Digesters			
Mixing	106.00	344.00	1,122.00
Heating	17.60	122.40	788.00
Vacuum Filtration	57.00	346.00	3,325.00
Multiple Hearth Incineration	54.00	245.00	1,905.00
LIGHTS AND MISCELLANEOUS POWER	57.00	210.00	2,400.00
TOTAL Kilowatt-hours/day	721.00	4,806.00	40,282.00

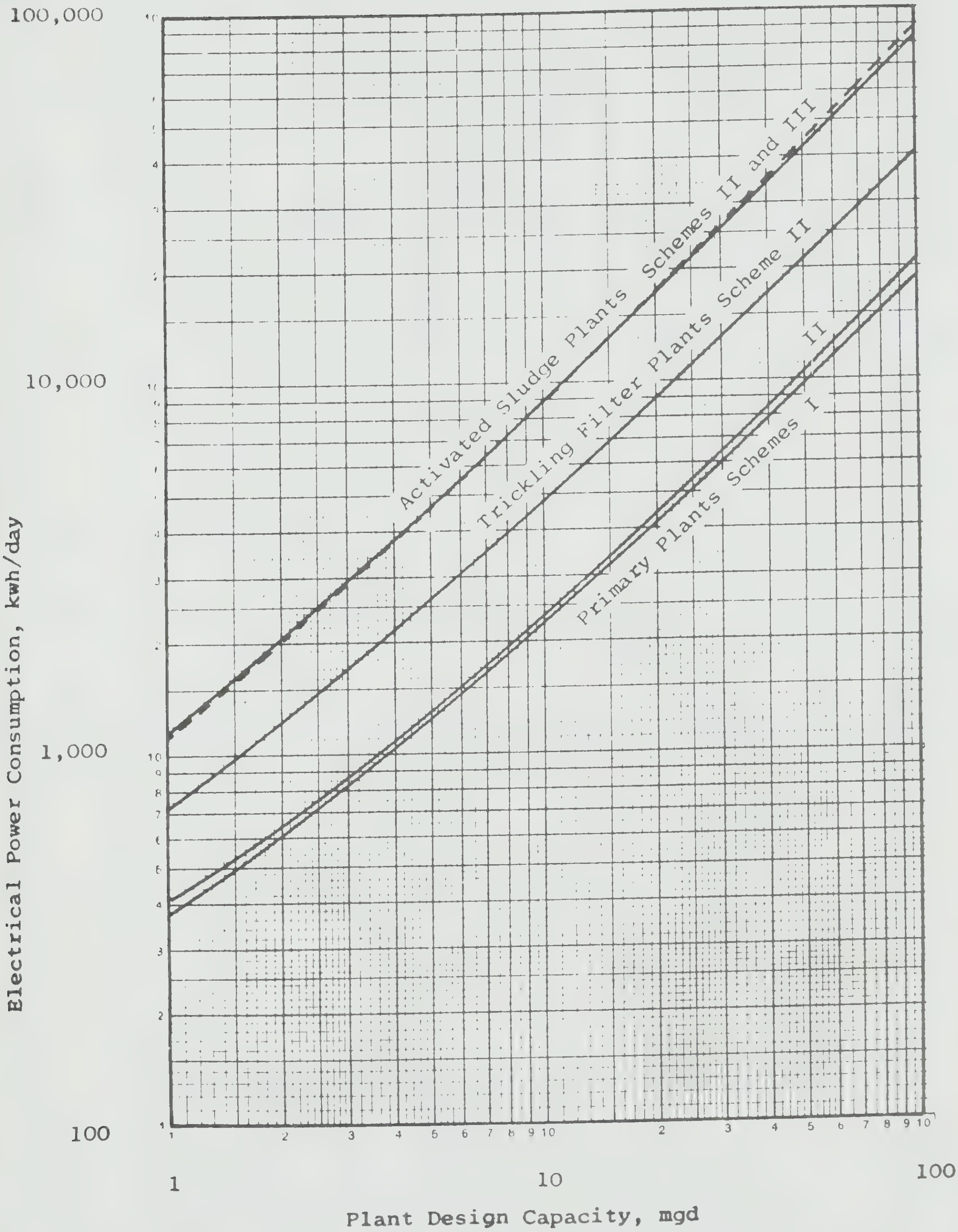


Figure 1

ELECTRICAL ENERGY CONSUMPTION BY MUNICIPAL WASTEWATER TREATMENT PLANTS
versus
PLANT SIZE[1]

TABLE 6

ESTIMATED ELECTRICAL POWER CONSUMPTION FOR ALTERNATIVE TERTIARY TREATMENT TRAINS AFTER SECONDARY TREATMENT

Plant Size - 1 mgd

ADVANCED PROCESSES USED	I	II	III	IV	V	VI	VII	VIII
Microscreening	115							
Alum Addition and Extra Sludge Handling		101	101					
Lime Clarification				52	52	52		52
Lime Sludge Dewatering				64	64	64		64
Lime Recalcination				254	254	254		254
Recarbonation								94
Ammonia Stripping								437
Nitrification		638	638					
Denitrification		10	10					
Multi-Media Filtration			100	100	100	100	100	100
Granular Carbon Adsorption					371	371		371
Carbon Regeneration					20	20		20
Electrodialysis								
Reverse Osmosis						1341	5993	
Total Power Consumption, kwh/day	115	749	849	470	861	[illegible]	[illegible]	1392

TABLE 7

ESTIMATED ELECTRICAL POWER CONSUMPTION FOR ALTERNATIVE TERTIARY TREATMENT TRAINS AFTER SECONDARY TREATMENT

Plant Size - 10 mgd

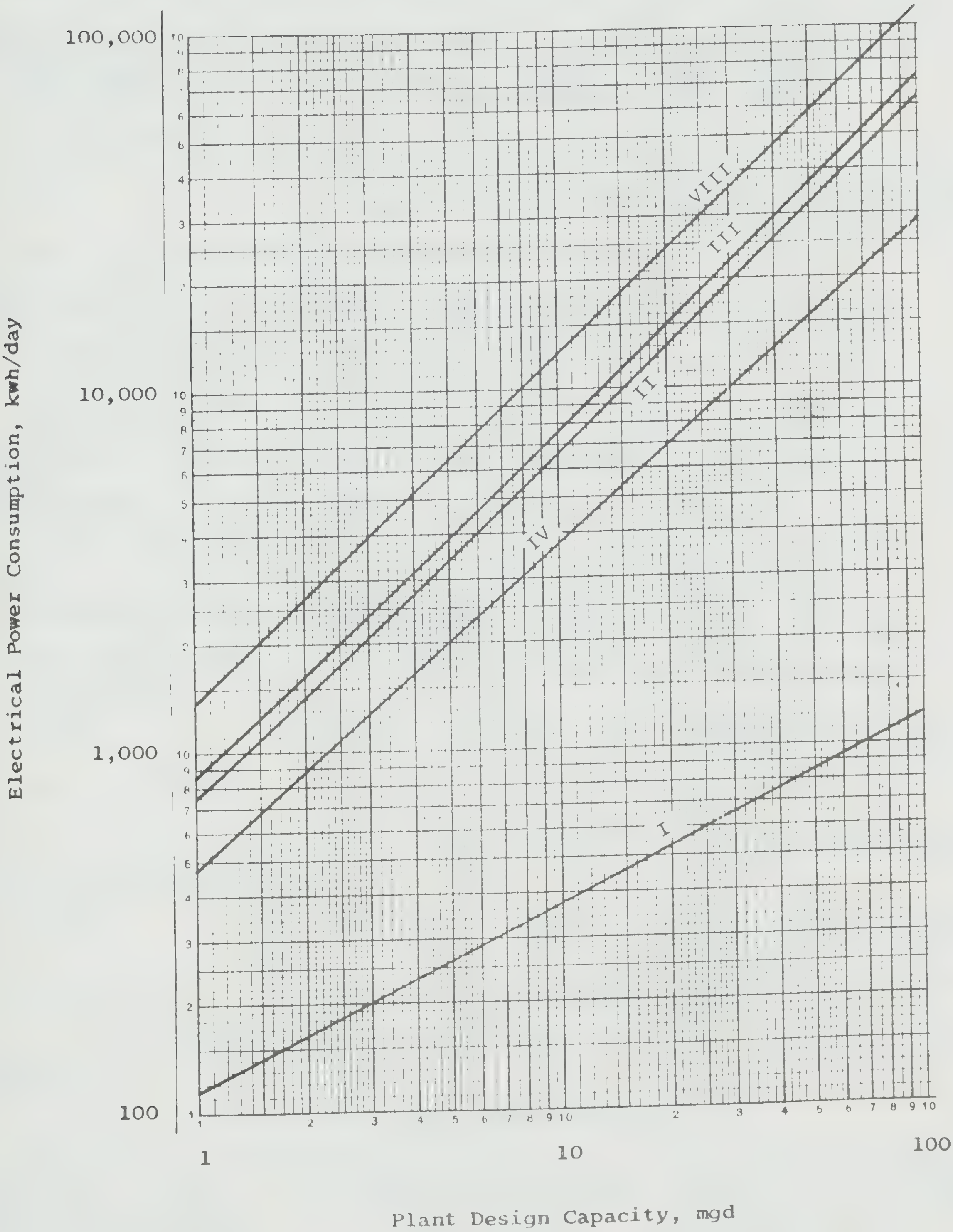
ADVANCED PROCESSES USED	I	II	III	IV	V	VI	VII	VIII
Microscreening	375							
Alum Addition and Extra Sludge Handling		333	333					
Lime Clarification				611	611	611		611
Lime Sludge Dewatering				637	637	637		637
Lime Recalcination				1570	1570	1570		1570
Recarbonation								936
Ammonia Stripping								4368
Nitrification		6235	6235					
Denitrification		102	102					
Multi-Media Filtration			953	953	953	953	953	953
Granular Carbon Adsorption					3511	3511		3511
Carbon Regeneration					155	155		155
Electrodialysis								
Reverse Osmosis						13,410	55,836	
Total Power Consumption, kwh/day	375	6670	7623	3771	7437	20,847	57,239	12,741

TABLE 8

ESTIMATED ELECTRICAL POWER CONSUMPTION FOR ALTERNATIVE TERTIARY TREATMENT TRAINS AFTER SECONDARY TREATMENT

Plant Size - 100 mgd

ADVANCED PROCESSES USED	I	II	III	IV	V	VI	VII	VIII
Microscreening	1,200							
Alum Addition and Extra Sludge Handling		2,518	2,518					
Lime Clarification				2,958	2,958	2,958		2,958
Lime Sludge Dewatering				6,370	6,370	6,370		6,370
Lime Recalcination				10,374	10,374	10,374		10,374
Recarbonation								9,355
Ammonia Stripping								43,680
Nitrification		60,259	60,259					
Denitrification		1,020	1,020					
Multi-Media Filtration			8,743	8,743	8,743	8,743	8,743	8,743
Granular Carbon Adsorption					31,548	31,548		31,548
Carbon Regeneration					1,175	1,175		1,175
Electrodialysis								
Reverse Osmosis						134,100	497,811	
Total Power Consumption, kwh/day	1,200	63,797	72,540	28,445	61,168	195,268	506,554	114,203



Note: I, II, III, IV, & VIII refer to specific treatment trains

Figure [illegible]

ELECTRICAL ENERGY CONSUMPTION FOR TERTIARY WASTEWATER TREATMENT TRAINS
versus
PLANT SIZE[1]

for an open system with a settling pond or from 10 to 25 kw/1000 gpm for a closed recycle system. An article by Honea[3] presents the table reproduced here as Table 9, listing the equipment and processes along with ranges for power requirements. Since most units operate on gravity flow with the exception of filters, pressure drops within a unit are not represented in Table 9.

Normally, systems of large size utilizing trickling or sand bed filters, thickeners, clarifiers and lagoons require either no power or a small amount for the spray arms or the rotating rakes. The major power consuming units are agitators, aerators, sludge dewatering filters, separaters, reverse osmosis units and distillation units. Values for energy consumption and the procedures for estimating these quantities can be obtained from the above references. A more precise level of estimation can be obtained using the manufacturers specifications in the case of a specific project where several alternative unit processes are available.

TABLE 9

WASTEWATER-TREATMENT EQUIPMENT

Equipment	Power	Remarks
Wastewater systems		
Closed system	10 to 25 kW/1,000 gal	Lund, Ref. 5
Open system-settling pond	5 to 10 kW/1,000 gal	Lund, Ref. 5
Agitators	Mild: 0.37 to 0.75 kW/1,000 gal	Power requirements based on water (will be higher for thick and viscous liquids)
Aerators		
General lagoon	0.5 to 20 kW/million gal	
Surface aerator	4 to 5.5 lb oxygen/kWh	
Submerged turbine		
Single impeller	2 to 2.7 lb/kWh	
Dual impeller	3.3 to 4 lb/kWh	
Screens		
Stationary	None	
Shaking, vibrating	0.04 to 0.10 kW/ft^2	
Filter		
Trickling, sand bed	None unless to drive spray arm	Gravity flow
Continuous, vacuum: belt or drum	Rotation: 0.04 kW/ft^2	Vacuum: 0.5 to 60 cfm/sq.ft
Intermittent: press	None	Pressure and or vacuum (up to 150 psi) See pump curve.
Clarifying, inline	None	Line pressure-drop: 0.1 to 10 ft
Thickeners and clarifiers		For settling and clarification
Gravity thickener, lagoons	None	Gravity flow
Thickener	0.4 to 12 kW/1,000 gpm	Discount 50% if continuous operation
Clarifier	0.4 to 12 kW/1,000 gpm	Discount 50% if continuous operation
Separators		
Centrifugal	0.2 to 25 kWh/ton solids	
Adsorption		
Zeolites, carbon Activated charcoal	Regeneration: 100 to 200 Btu/h per lb dry adsorbent	Regeneration or discard rate dependent on contaminant concentration and water throughput
Distillation	50 to 1,200 Btu/lb	Depends on vapor pressure heat of vaporization of liquid
Reverse Osmosis	None	Pressure required to 100 psi
Chemical Treatment	Metering pumps, agitation (mixing)	Power depends on feed rates low except for lime slaking operations

3.0 Chemical Production and Power Requirements

The above mentioned studies on energy requirements considered only the electrical operating energy for the systems involved. A more complete analysis of the operating energy should include the energy expenditure in the commercial manufacture of the chemicals required in these processes. The conventional treatment processes usually use chlorine as a disinfectant. Alum and Lime are used to coagulate suspended material and precipitate phosphorus.

For comparison and utilization of the data compiled by Smith[1], power requirements for production of alum, lime and chlorine are calculated on the basis of dosage and wastewater treatment plant capacity. The values of loadings for use with Smith's data are 1, 10 and 100 mgd. The primary reference for the plant power requirements is the text by Shreve, "Chemical Process Industries". The energy data as shown on the flow sheets are given in terms of kilowatt-hours per ton of product. The following sections illustrate the energy requirement calculations for these chemicals.

3.1 Energy Requirements for Alum Production

According to Shreve[4] practically all alums and aluminum sulphate are made now from Bauxite by reaction with 60 Bé (sp. gr. 1.7) sulphuric acid. Figure 3 shows a flow diagram of this process[4] with its mass and energy balance.

On the basis of:

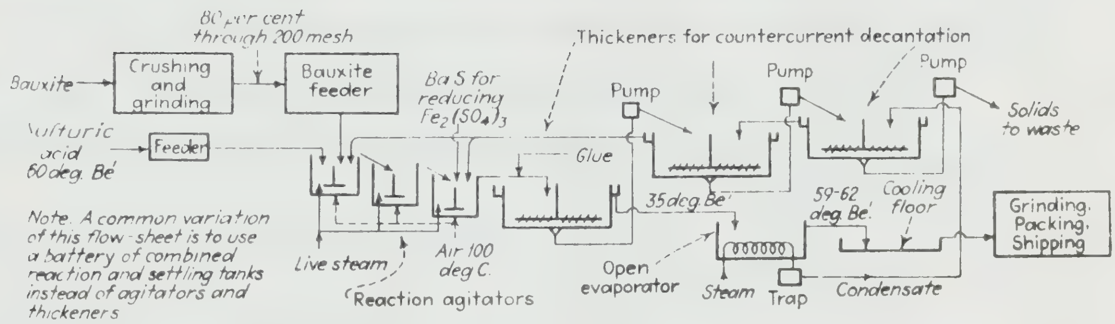
1 ton of 17% Al_2O_3 Alum,

1 mgd wastewater treatment capacity,

the power requirements are:

Electricity - 29 kwh/ton Alum

Coal (for steam) - 640 lb/ton Alum



Bauxite (55 per cent Al_2O_3)	670 lb	Per ton of 17 per cent Al_2O_3 "alum"
H_2SO_4 (60 deg. Bé.)	1,140 lb.	
Black ash (70 per cent BaS)	13 lb	
Flake glue	0.4 lb.	
Coal (steam)	640 lb.	
Electricity	29 Kw.-hr	
Direct labor	1.5 man-hr.	

Figure 3 Manufacture of Aluminum Sulfate by the Dorr Procedure.[4]

An average heating value for coal is 11,790 BTU/lb[5].

The heat produced by burning coal is

640 lb/ton Alum x 11,790 BTU/lb = 7.55×10^6 BTU/ton Alum.

In units of kilowatt-hours, the energy requirement is

$E_{Alum} = 7.55 \times 10^6$ BTU/ton Alum x 2.928×10^{-4} kWh/BTU

$= 2.21 \times 10^3$ kWh/ton Alum (7.96×10^9 joules/ton Alum)

Compared to this value, electrical energy requirements are negligible and can be ignored in the calculation. According to Smith[1], a dosage of 144 mg/l dry Alum is used in his study based on Lake Tahoe data. For a flow of 1 mgd, or 3.785×10^6 l/day, the Alum required is

3.785×10^6 l/day x 144 mg/l = 5.45×10^8 mg/day,

or 0.601 tons Alum/day.

Thus, the total energy required for Alum production for a 1 mgd system is

2.21×10^3 kWh/ton Alum x 0.601 tons Alum/day,

$= 1.327 \times 10^3$ kWh/day (4.78×10^3 joules/day)

For 10 and 100 mgd systems, the energy values are 1.327×10^4 and 1.327×10^5 kWh/day respectively.

3.2 Energy Requirements for Lime Production

The calcining process produces lime from limestone according to the reactions:

1. Calcining:

$CaCO_3(s) \rightleftarrows CaO(s) + CO_2(g)$ $\Delta H_{1200-1300}$ ^0C = +4.25 million BTU/ton lime prod.

2. Hydrating:

$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$ H = -15.9 kcal

For the burning of lump limestones upright kilns are usually employed, but are known to suffer from uneven heating and blocking of burning gas. Horizontal revolving kilns are more costly but result in improved performance. The travelling grate-kiln system of Allis-Chalmers Mfg. Co. requires 6 million BTU from natural gas per ton of lime[4]. The auxillary energy requirements for conveying and other pretreatment and post-treatment processes are negligible in comparison.

Using again a basis of 1 ton of lime and a treatment plant of 1 mgd, the energy required for the calcining process is

$$E_{lime} = 6 \times 10^6 \text{ BTU/ton} = 1.757 \times 10^3 \text{ kwh/ton lime}$$
$$(6.325 \times 10^9 \text{ joules/ton lime})$$

The lime required for a 1 mgd plant requiring a dosage of 200 mg/l lime is

$$200 \text{ mg/l} \times 3.785 \times 10^6 \text{ l/day} = 7.57 \times 10^8 \text{ mg/day}$$
$$= 0.8344 \text{ tons/day}$$

Therefore the major quantity of energy required for lime production for 1 mgd is

$$1.757 \times 10^3 \text{ kwh/ton lime} \times 0.844 \text{ tons lime/day}$$
$$= 1.466 \times 10^3 \text{ kwh/day} \quad (5.278 \times 10^9 \text{ joules/day})$$

For 10 and 100 mgd systems, the energy requirements are 1.466×10^4 and 1.466×10^5 kwh/day, respectively.

3.3 Energy Requirements for Chlorine Production

Figure 4 shows the flow diagram for the production of chlorine by the caustic-chlorine process from sodium chloride[4]. The material and energy balance shows that the production of 1 ton of caustic, 1,750 lb chlorine and 8,750 ft^3 (50 lb) hydrogen requires:

1. 3,000 kwh electricity
2. 20,000 lb steam at 75 to 100 psig[5]

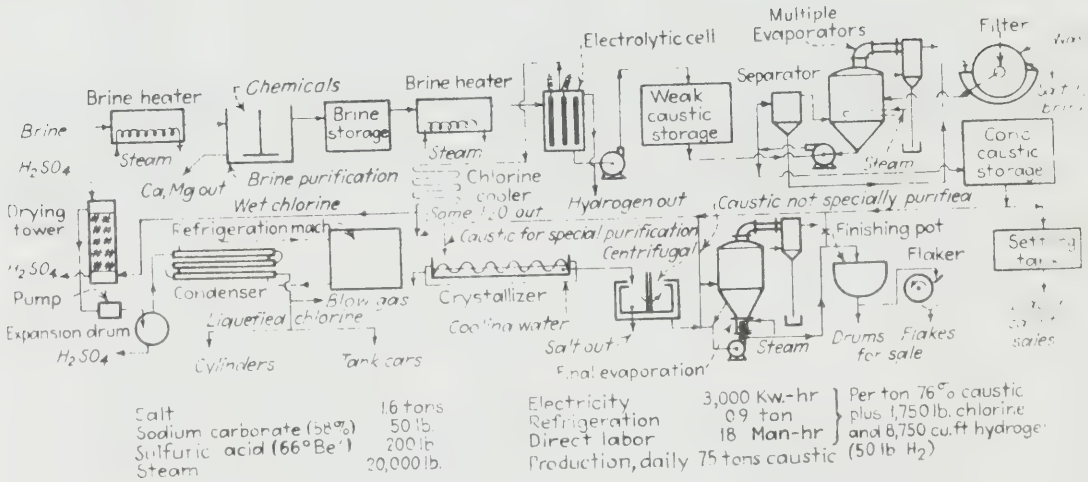


Figure 4 Flowchart for Disphragm Caustic Soda and Chlorine Cell.[4]

The energy required to produce 20,000 lb of 100 psig saturated steam

is $\quad 2 \times 10^{4}$ lb steam x 1187.2 BTU/lb steam (steam tables)

$= 2.374 \times 10^{7}$ BTU

or 6.95×10^{3} kWh/total product. The total weight of product (chlorine + caustic + hydrogen) is

1,750 lb + 2000 lb + 50 lb = 3.80×10^{3} lb or 1.90 tons.

The percent chlorine produced = 1,750 lb/3,800 lb x 100% = 46%.

The energy per ton product from steam is

$$E_{Cl}^{st} = 6.95 \times 10^{3} \text{ kWh/1.9 tons} = 3.66 \times 10^{3} \text{ kWh/ton} \quad (1.318 \times 10^{10} \text{ joules/ton})$$

The electrical power is 3,000 kWh/1.9 tons = 1.579 kWh/ton.

The total energy requirement is

$$E_{Cl}^{tot.} = E_{Cl}^{st} + E_{Cl}^{el} = 3.66 \times 10^{3} + 1.579 \times 10^{3}$$

$$= 5.24 \times 10^{3} \text{ kWh/ton } (1.886 \times 10^{10} \text{ joules/ton})$$

Since chlorine is 46% of the total product, assume for approximation purposes that 46% of the total energy is required to produce chlorine: that is;

$$46/100 \times 5.15 \times 10^{3} = 2.41 \times 10^{3} \text{ kWh/ton } Cl_2$$

For a wastewater treatment plant of 1 mgd capacity and a dosage of 10 mg/l chlorine, the chlorine requirement is

$$3.785 \times 10^{6} \text{ l/day} \times 10 \text{ mg/l} = 3.785 \times 10^{7} \text{ mg/day}$$

or $\quad 4.17 \times 10^{-2}$ tons/day.

Therefore, the energy required for chlorine for this plant capacity is

$$2.41 \times 10^{3} \text{ kWh/ton Cl} \times 4.17 \times 10^{-2} \text{ tons } Cl_2\text{/day}$$

$$= 99.0 \text{ kWh/day } (3.56 \times 10^{8} \text{ joules/day}).$$

For 10 and 100 mgd, the values are 990 and 9900 kWh/day respectively.

3.4 Results of Calculations

The data for chemical operating energy were added to Smith's data to obtain the total energy requirements for the various treatment configurations. These data are presented in Tables 10 and 11 along with the percentage contributed by the chemical operating energy. Figures 5 and 6 show the total power consumption for each of the systems and their variation with plant capacity.

TABLE 10

CONVENTIONAL TREATMENT SYSTEMS

Type	Energy and Sludge Handling Scheme	1 mgd	10 mgd	100 mgd
Primary	a. Electrical Energy I	372	2293	18,700
	b. Chemical Energy - Cl_2	99	990	9,900
	Total	471	3283	28,600
	% Chemical Energy	21%	30%	35%
Primary	a. Electrical Energy II	411	2343	21,000
	b. Chemical Energy - Cl_2	99	990	9,900
	Total	510	3333	30,900
	% Chemical Energy	19%	29.7%	32%
Activated Sludge	a. Electrical Energy II	1,115	8809	81,094
	b. Chemical Energy - Cl_2	99	990	9,900
	Total	1,214	9799	90,994
	% Chemical Energy	8%	10%	11%
Activated Sludge	a. Electrical Energy III	1,085	9044	85,862
	b. Chemical Energy - Cl_2	99	990	9,900
	Total	1,184	10,034	95,762
	% Chemical Energy	8%	9.9%	10.3%
Tricking Filter	a. Electrical Energy II	721	4806	40,282
	b. Chemical Energy - Cl_2	99	990	9,900
	Total	820	5796	50,182
	% Chemical Energy	12%	17%	20%

TABLE 11

ADVANCED TREATMENT SYSTEM

Process	Energy		1 mgd	10 mgd	100 mgd
I	a.	Electrical	115	375	1,200
II	a.	Electrical	749	6670	63,797
	b.	Alum	1,327	13,270	132,700
		Total	2,076	19,940	196,497
		% Chem.	64%	67%	68%
III	a.	Electrical	849	7623	72,540
	b.	Alum	1,327	13,270	132,700
		Total	2,176	20,893	205,240
		% Chem.	61%	63%	65%
IV	a.	Electrical	470	3771	28,445
	b.	Lime	1,466	14,660	146,600
		Total	1936	18,431	175,045
		% Chem.	76%	80%	84%
V	a.	Electrical	861	7437	61,168
	b.	Lime	1466	14,660	146,600
		Total	2327	22,097	207,768
		% Chem.	63%	66%	71%
VI	a.	Electrical	2202	20,847	195,268
	b.	Lime	1466	14,660	146,600
		Total	3668	35,507	341,868
		% Chem.	40%	41%	43%
VII	a.	Electrical	6003	57,239	506,554
VIII	a.	Electrical	1392	12,741	114,203
	b.	Lime	1466	14,660	146,600
		Total	2858	27,401	260,803
		% Chem.	51%	54%	56%

Figure 5

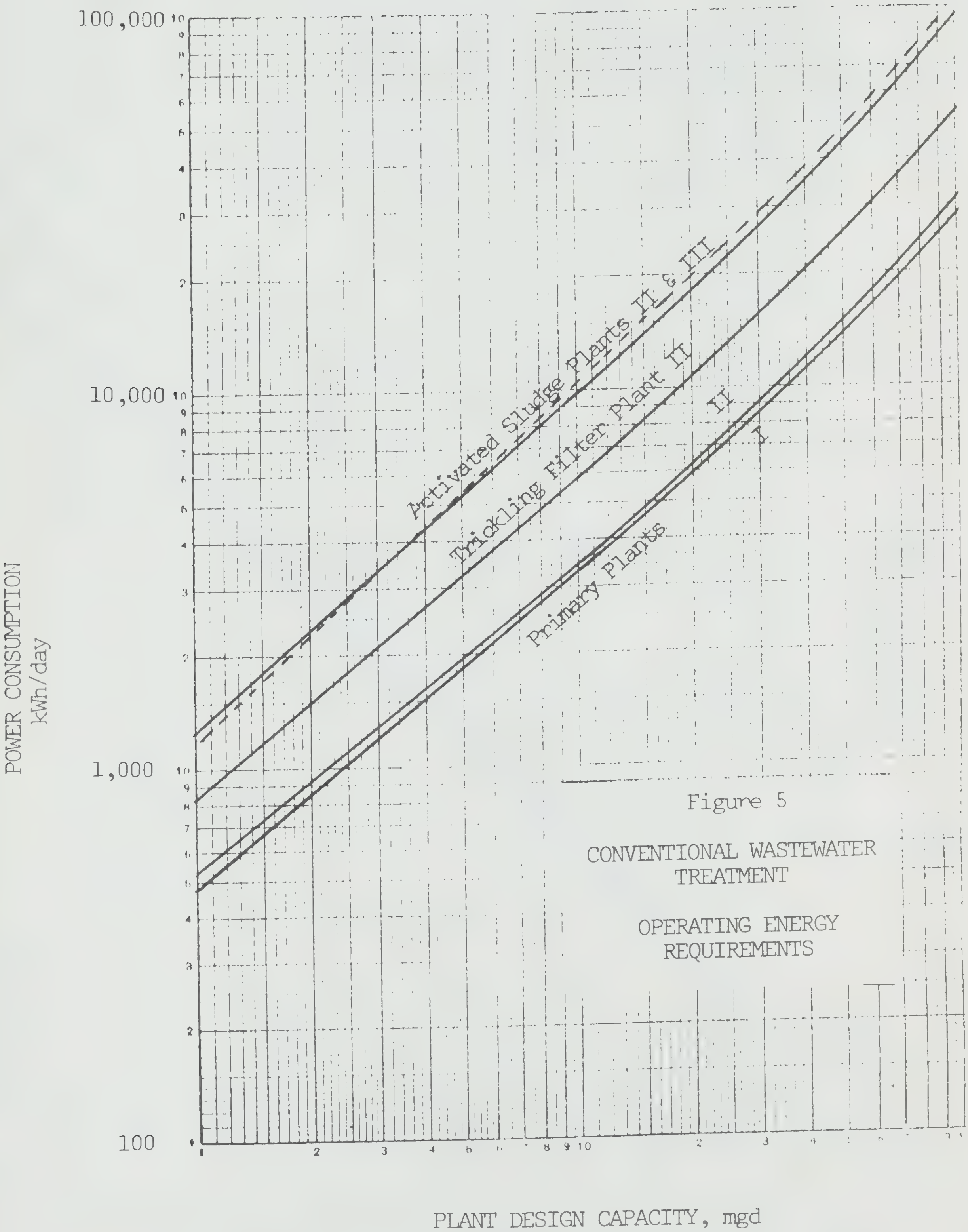
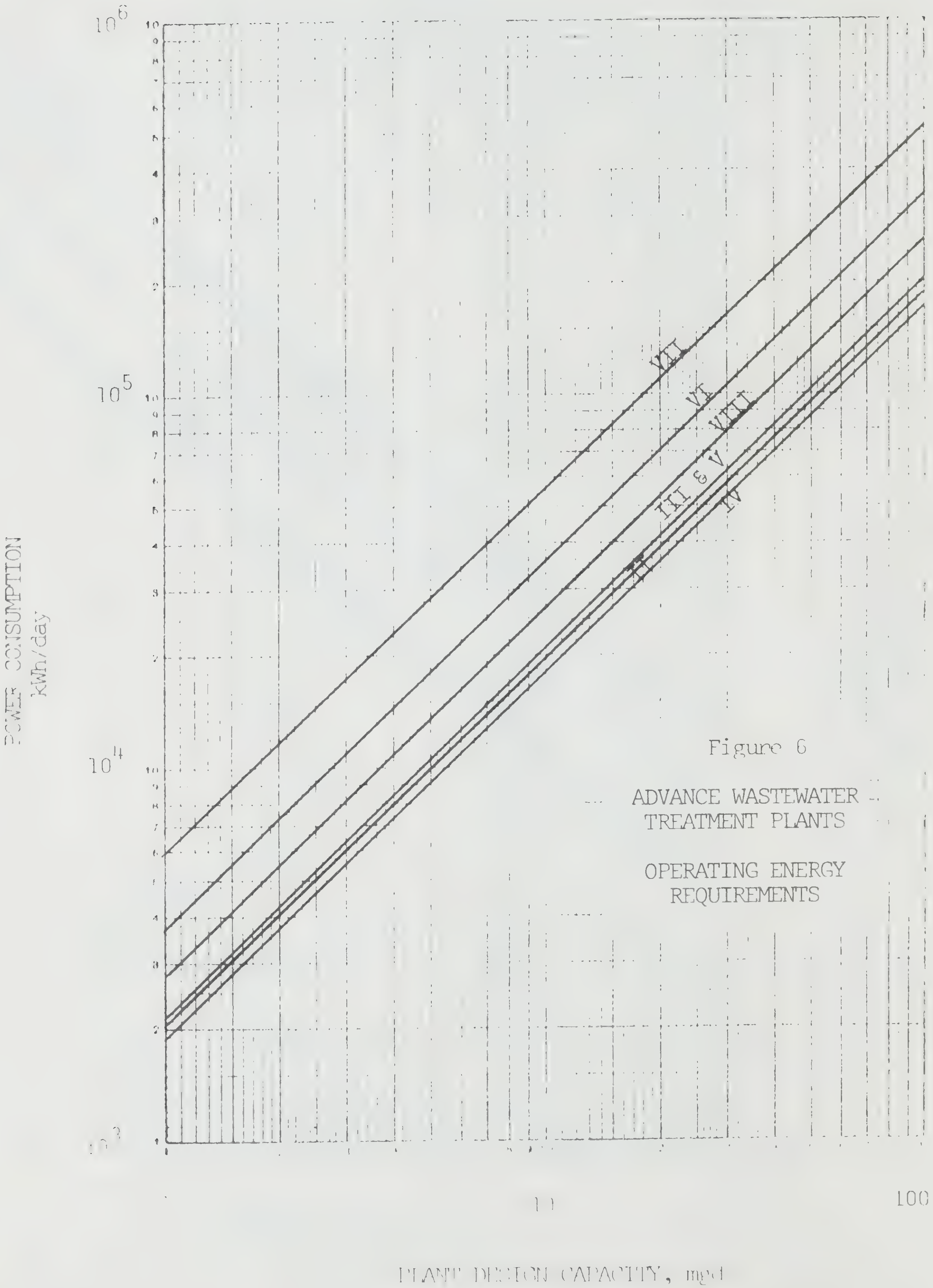

100,000
10,000
1,000
100
POWER CONSUMPTION
kWh/day
Activated Sludge Plants II & III
Trickling Filter Plant II
II
I
Primary Plants
Figure 5
CONVENTIONAL WASTEWATER
TREATMENT
OPERATING ENERGY
REQUIREMENTS
PLANT DESIGN CAPACITY, mgd

Figure 6



10^6
10^5
10^4
10^3
POWER CONSUMPTION kWh/day
VII
VI
VIII
III & V
IV
II
Figure 6
ADVANCE WASTEWATER TREATMENT PLANTS
OPERATING ENERGY REQUIREMENTS
10
100
PLANT DESIGN CAPACITY, mgd

3.5 Comparison of Data

3.5.1 Conventional Treatment Systems

The curves plotted in Figure 5 are similar to those in Figure 1 for conventional systems but are shifted upward reflecting the increase in operating power resulting from the use of chlorine. The increase in power requirements due to the inclusion of the production energy of chlorine was in the range from 8% to 33% for the 1 to 100 mgd systems. The highest energy increases are for primary treatment systems which have the lowest electrical energy requirement. The chemical energy increases for the activated sludge systems are the lowest of all the conventional systems investigated.

The overall percent increase in energy requirements increases concave upward with increasing treatment plant capacity but is a result of the nonlinear increase in electrical power demands with increasing plant capacity; whereas, the chemical energy increment is a linearily increasing function with respect to the plant capacities.

The process with the lowest power increment due to the chlorine addition was the activated sludge system using sludge handling scheme III involving air floatation thickeners.

3.5.2 Advanced Treatment Systems

The power increment as a result of lime and alum addition falls in the range of 40 to 84%. From Table II, increments above 50% are indications that the power required for chemical production is greater than the electrical power required by the treatment systems.

The increase in energy percentage from chemical sources with plant capacity also show the same trends as discussed above for the conventional systems.

4.0 Discussion and Conclusions

Examination of Figure 5 and 6 show that the total operating energy requirements of the advanced systems are, in the large, an order of magnitude greater than the conventional systems. The study published by Smith shows the electrical energies to be of the same order of magnitude for both systems. The increases in operating energy due to chemical usage must be taken into account since the basis of the advanced treatment is the rapid clarification by chemical means. Although the dosage values are average, they reflect the large quantity of power which must be put into their production.

It is expected that design and feasibility analysis of future treatment systems will lay heavy emphasis on both capital and operating energy requirements for assessment of applicability as well as functional design and cost estimation. The decision to use conventional or advanced treatment will also be dependent on the energy demands of the system with respect to the existing and future energy situations.

References

1. Smith, Robert — "Electrical Power Consumption Wastewater Treatment", E.P.A. Report R2-73-281, July, 1973, National Environmental Research Center, U.S. Office of Research and Monitoring, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

2. Lund, H.T.(Ed) — "Industrial Pollution Control Handbook", McGraw-Hill Book Co., N.Y., 1971.

3. Honea, F.I. — "Energy Requirements for Environmental Control Equipment", Chemical Engineering, 22, 55, October 21, 1974.

4. Shreve, R.N. — "Chemical Process Industries", McGraw-Hill Book Co., N.Y. 1967.

5. Perry, R.H.(Ed) — "Chemical Engineers' Handbook", 4th Ed. McGraw-Hill Book Co, 1963.